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Rates and patterns of deforestation in the Philippines: application of geographic information system analysis

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ABSTRACT

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Land-use maps for 1934 and 1988, and a 1941 road map of the Philippines were digitized into a geographic information system. These maps were then analyzed to determine the rates of deforestation and their relationship with factors such as the distance of forests to roads and forest fragmentation (measured by perimeter-to-area ratio (P/A ratio) of forest patches) for this country. The Philippines lost a total of 9.8 million ha of forests from 1934 to 1988.The presence of major roads was a very important factor affecting deforestation. The closer a forest was to roads, the higher the rate of deforestation. Nearly 78% of the 2.1 million ha of forests within 1.5 km of roads in 1934 was removed by 1988. By contrast, only 39.5% of forest was lost between 15.0 and 16.5 km from roads. The density of roads per unit area did not predict deforestation as well as the distance of forest patches to roads. The P/A ratio of forest patches was also useful for assessing their rate of clearing. The larger the P/A ratio of a forest patch, the more likely it was to be cleared. Forests with P/A ratios greater than 65 m ha^{-1} in 1934 had all disappeared by 1988. Forests with large P/A ratios were also characterized by small area and the presence of adjacent agricultural lands in 1934. They were readily cleared and never reforested.

INTRODUCTION

Because of the ecological importance of tropical forests, their rapid destruction has raised increasing concern in the global community. Many studies have investigated rates of forest clearing and their respective causes. These studies were mainly accomplished by analyzing a time-series of satellite imagery (e.g. Malingreau and Tucker, 1987; Nelson et al., 1987; Stone et al.,

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1991) or a time-series of land-use maps (e.g. Sader and Joyce, 1988; Harrison, 1991; Iverson, 1991; Brown et al., 1992). Several of these studies have shown that roads have been a very significant factor influencing deforestation. Road building increased the likelihood of deforestation in Costa Rica (Sader and Joyce, 1988) and Brazil (Stone et al., 1991). It is commonly believed that the closer a forest is to roads, the more likely it is that it will be cleared. However, no study has reported on the relationship between deforestation rate and where it occurs in relation to road networks.

Other studies have also revealed that the perimeter-to-area (P/A) ratio of forest patches was often correlated with the degradation of forest. For example, Brown et al. (1992) found that an increase in the P/A ratio of forest patches between 1972 and 1982 in Peninsular Malaysia was associated with a decrease in biomass density (biomass per unit area) of the forests. Yet, no evidence has been reported on how deforestation correlates with the P/A ratio.

The Philippines is one of the countries undergoing severe forest loss (Food and Agriculture Organization (FAO) 1981), but the mechanisms of loss are generally unknown. The objectives of this research were to use geographic information system (GIS) techniques to understand the factors leading to deforestation in the Philippines. Specific questions that were addressed are: (1) how fast have the Philippine forests been cleared? (2) how is the distance of forests from roads correlated with the rate of forest clearing? (3) how are the P/A ratios of forest patches correlated with forest clearing? Understanding how these factors influence tropical deforestation is crucial for a more accurate assessment of the problem and for guiding decision-makers on land-use planning.

THE PHILLIPINES AND ITS FORESTS

The Philippines, located between the equator and the Tropic of Cancer in Southeast Asia, is one of the largest archipelagoes in the world. With approximately 7100 islands, the land area of this country is 299 400 km^2 (FAO, 1981; Baconguis et al., 1990). It comprises three major island groups: Luzon, Visayas and Mindanao. The main types of forest vegetation of the Philippine islands are dipterocarp, mangrove, pine and mossy (or cloud forests). Most of the commercially valuable species are members of the Dipterocarpaceae (Ooi, 1987; Garrity et al., 1992).

Disappearance and degradation of forests are among the most significant issues of natural resources management in the Philippines. The country was 90% forested when the Spaniards conquered the islands in the middle of the sixteenth century (Westoby, 1989). By 1900, forest cover was reduced to 70% (Garrity et al., 1992). The establishment of plantations of export crops led to a tremendous loss of forests in the nineteenth century. During World War II, forest logging decreased because of the decline of the timber industry. On the other hand, forest clearing increased because a large number of Filipinos took refuge in the forests and practiced farming therein. The overall effect of these factors on forest cover is unknown (Garrity et al., 1992).

During the post-war years from 1945 to 1953, the Philippines experienced economic reconstruction with concomitant rapid and widespread forest exploitation and deforestation (FAO, 1989). Forest harvesting was unrestricted at that time; log exportation was unrestricted after the late 1940s. The only forest management control imposed was that the minimum diameter of the trees to be cut was 50 cm. When logging was mechanized, even this minor regulation was ignored. This vast forest destruction continued until the 1950s, when the selective logging system was initiated. Even at that time, many people still thought that forests were inexhaustible no matter how much volume was removed from them.

In the early 1970s, over 170 000 ha of forest lands was destroyed annually, but less than 5% of that area was reforested (Bunge, 1984). In the late 1970s, the emphasis began to shift from timber harvesting and utilization to the protection, rehabilitation, and development of forest lands. The Philippines' Bureau of Forestry Development of the Ministry of Natural Resources prescribed an annual allowable cut for each logging concession. As a result, from 1975 to 1981, log production steadily decreased according to official statistics, but illegal logging was widespread (Kummer, 1992). In 1982, the Bureau further reduced the annual allowable cut for most timber concessions and log export was also restricted. However, illicit logging still occurs (Abate, 1992).

The main causes of deforestation and degradation of forests in the Philippines have been attributed to shifting cultivation, unorganized encroachment on forest lands, squatting, migration of landless lowlanders into upland forested areas, and government-sponsored settlement schemes (Ooi, 1987). However, more recent analysis suggests that a combination of commercial logging followed by 'frontier' agriculture is the main cause (Kummer, 1992). Much of deforestation is associated with the conversion of forest lands to agriculture and mangroves to aquaculture lands. For example, 75% of the mangrove vegetation which existed in 1918 had been converted to fishponds and other landuses by 1987 (Baconguis et al., 1990). Rapid population growth, landlessness, poverty and lack of unoccupied arable lowland created pressure for the immigration from lowland to upland areas (Acosta, 1989; World Bank, 1989). Now, about one-third of the Filipinos are upland dwellers, half of whom are farming on former forest lands.

METHODS

Data sources

Two land-use maps were acquired for determining the rate of forest clearing. The first map was compiled at a scale of 1 : 1 600 000 by the Philippine

Bureau of Forestry, Department of Agriculture and Commerce, based on 1934 survey data (Fischer, 1934). No further written records on this map were available. The second map was compiled by the Swedish Space Corporation (SSC) and was based on the interpretation of 187 images from Satellite Pour l'Observation de la Terre (SPOT) recorded during 1987–1988, and on ground reference data (SSC, 1988). Most of the images used for this map were from 1987, and the ground reference data were acquired in the 1987 dry season by aerial reconnaissance and ground surveys. The map scale is 1:2 000 000. Another current forest map is available (German–Philippine Project), but we decided to use the Swedish one because it was based on satellite imagery collected over about a 1-year period versus 6 years for the German–Philippine product.

The 1934 land-use map identified seven types of land, three of which were forests: commercial forest; non-commercial forest; pine forest. The 1988 land-use map had four groups of land cover: forest; extensive land use; intensive land use; non-vegetated lands and other areas. The forest group consisted of five classes: closed dipterocarp (mature trees covering $\geq 50\%$); open dipterocarp (mature trees covering $< 50\%$); mangrove; pine; mossy (SSC, 1988). Also shown on the 1988 land-use map were the boundaries of 13 administrative regions.

Finally, a 1941 official road map of the Philippines at a scale of 1:2 000 000 was obtained. This map is the closest one available in time to the 1934 land-use map. In addition to railroads, this map shows four types of roads: first class; second class; third class; trail (Bureau of Public Works, 1941). It was produced using road diagrams and maps submitted by the district engineers. Data on trails were derived from various sources.

Building the GIS data base

The two land-use maps, the 1941 road map, and the boundaries of the 13 administrative regions shown on the 1988 land-use map were manually digitized using a vector-based GIS software package. They were then transformed to the Albers conic equal-area projection coordinate system and independently stored in digital format in the computer.

The next step was to unify the classification systems used on the two maps. The three forest types on the 1934 map and the five forest types on the 1988 map were treated as one class, and all other classes were grouped as one. This aggregation left two broad classes, forest and non-forest, on each of the land-use maps. This grouping enabled us to use these maps for determining the temporal trends of deforestation by avoiding the disagreement of different classification schemes.

Four types of transportation corridors (first class road, second class road, third class road and railroad) on the 1941 road map were also digitized. The trials were not digitized because their impact on deforestation was not comparable with that of the other four types and the source of information for mapping trials was not very reliable (Bureau of Public Works, 1941).

Deforestation and roads

A buffer is an area around a road within a certain distance. In this study, 17 buffers were created at 1.5-km intervals around the 1941 road network. The largest buffer, which included the land area within 25.5 km of roads, covered almost all of the Philippine land area except remote islands. These buffers were then overlaid on the 1934 and 1988 forest/non-forest maps, respectively. Overlaying is a technique used to combine two layers of coverage into a single coverage containing the information from both layers.

The concept of a buffer ring was developed. A buffer ring is the area remaining after subtracting a smaller buffer from a larger buffer. The buffer rings of roads can be used to study the pure effects of roads on deforestation. For example, the buffer ring created by subtracting the 1.5-km buffer from the 3.0-km buffer can show the impact of roads on forests located 1.5–3.0 km from roads. On the other hand, the 1.5- or 3.0-km buffers consider the entire area from the road to the buffer distance and only show the cumulative impact of roads on deforestation.

Seventeen buffer rings were created this way. The forest areas for 1934 and 1988, as well as the changes and percentage changes in forest area between 1934 and 1988, were calculated for each buffer ring. Least-squares regression analysis of percentage of forest clearing versus the distance of buffer rings to roads (the distance from road to the central line of a buffer ring) was used to test the hypothesis that the closer a forest is to a road, the greater the rate of deforestation.

Next, the boundaries of the 13 administrative regions, in digital format, were overlaid on the road map and land-use maps of 1934 and 1988. With the overlaid maps, road densities (length of road per unit area of land), the forest area in 1934, and the forest area in 1988 were calculated for each administrative region. These data were then used to analyze the relationship between deforestation and road density by administrative region.

Deforestation and perimeter-to-area ratio

A polygon stored in a vector GIS format has two primary geometric measurements, perimeter and area. We hypothesized that for a forest patch of a given size, the longer the perimeter (that is the more edge exposed to humans) the more likely it is to be cleared. The perimeter-to-area ratio (P/A ratio) is therefore used as a spatial measure expressing how much edge per unit area is exposed to humans. However, P/A ratios are not fixed, and they

TABLE 1

Area loss for different geometric shapes with different areas but the same perimeter-to-area ratio (P/A = 1.585)

Encroaching distance	Circle (area = 5.00)		Equilateral triangle (area = 8.27)	
	Absolute area loss	Relative area loss (%)	Absolute area loss	Relative area loss (%)
0.1	0.76	15.22	1.25	15.22
0.2	1.45	29.19	2.41	29.19
0.3	2.09	41.90	3.46	41.90
0.4	2.66	53.36	4.41	53.36
0.5	3.17	63.55	5.25	63.55
0.6	3.62	72.50	5.99	72.50

vary with both shape and area. Two different conditions can result in high P/A ratios: the patch may have an extremely irregular boundary, regardless of size, or the patch may simply have a very small area, regardless of shape. Nonetheless, we can show through hypothetical examples that the P/A ratio is still a valid measure to describe patterns of area loss. With a simple computer program, we can simulate and calculate the area loss in a polygon as its size is gradually, but uniformly, reduced (encroaching distance). Examples of this simulation for two different patch shapes (a circle and an equilateral triangle) are shown in Table 1. These polygons were constructed to have the same P/A ratio, but they have different areas in order to have the same P/A ratio. For any given encroaching distance, the absolute area losses are different, but the relative area losses are exactly the same for both shapes. This rule was tested for several size classes and P/A ratios, and it held true in each case. These analyses show that P/A ratio can be used as a valid measure of relative area loss of forests regardless of the area's shape and size.

Perimeter-to-area ratios were calculated for the forest patches shown on the 1934 land-use map. The 1934 map was then overlaid with the 1988 land-use map. On the resultant map, we determined which forests in 1934 had been cleared by 1988 and which remained as forest. With the P/A ratios of forests in 1934 and the losses of forests between 1934 and 1988, the relationship between the P/A ratio and the relative forest clearing was assessed.

RESULTS AND DISCUSSION

General rate of deforestation

The total land area calculated from the digitized map was 29.78 million ha. This value is 0.5% less than the officially reported land area of the Philippines because some of the remote, tiny islands in the 1934 and 1988 land-use maps were not digitized. In 1934, the total area of all types of forests was calculated to be 17.07 million ha, or 57% of the total land area. In 1988, the calculated area for all types of forests was 7.30 million ha, or 24% of the total land area. Therefore, 9.77 million ha of forest was cleared from 1934 to 1988, with an average annual deforestation rate of 180 959 ha. More than half (57.2%) of the forests in 1934 had disappeared by 1988 (Fig. 1). Annual deforestation rates have not been constant over this time-period. For example, prior to 1969, deforestation was estimated to be <2% per year compared to 2.5% per year during the 1970s to 1980s; annual rates up to 3.5% per year were reported for 1976–80 (Kummer, 1992).

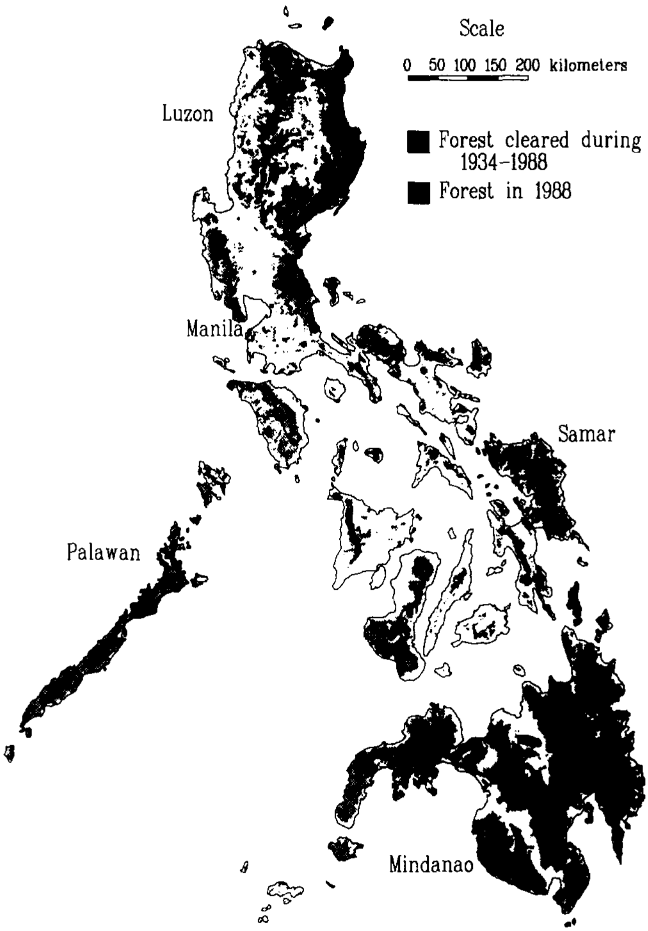

Fig. 1. Patterns of deforestation in the Philippines during 1934–1988. The forest area in 1934 is the sum of forests present in 1988 and the forests cleared between 1934 and 1988.

Deforestation and buffer distance from roads

The percentage of forest loss decreased linearly with increasing distance of the buffer ring to roads for the areas within 16.5 km of roads (Fig. 2). Nearly 78% of the 2.1 million ha of forests within 1.5 km of roads in 1934 was cleared by 1988, while only 39.5% of the forests between 15 and 16.5 km from roads was cleared. Over 17% of the total forest clearing occurred within 1.5 km of roads, and more than 50% was within 6 km (Table 2).

For areas beyond 16.5 km, no significant relationship was found and the relative forest loss fluctuated slightly at about 40% (Fig. 2). Clearly, something besides the impact of roads was more effective in explaining deforestation in these areas. Inspection of the overlaid map of land use and road buffers revealed that at the buffer width of 16.5 km, the buffer of the 1941 road network covered most of the land area of the Philippines (>84%, Table 2). Buffer rings beyond this distance had a significant portion of their area falling onto the seas. Further inspection of the land-use maps of 1934 and 1988 showed that deforestation also advanced inward from the seas; the closer an area was to the sea, the more deforestation (Fig. 1). These deforestation activities were probably associated with the clearing of mangrove and beach vegetation and their conversion to fishponds.

Deforestation and road density

Although nearness to roads affected forest loss, the relationship between road density (length of road per unit area) and relative forest loss was not

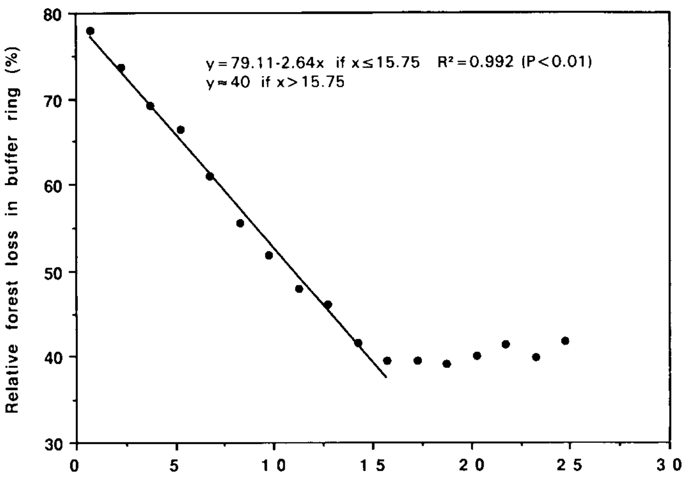

Fig. 2. The relationship between the relative forest losses in buffer rings during 1934–1988 and the distances of buffer rings to roads for the Philippines. The relative forest loss in a buffer ring is defined as the percentage of forest loss relative to the forest area in the buffer ring in 1934.

TABLE 2

Forest area and forest loss in buffer rings during 1934–1988 for the Philippines. (Total land area covered by all the buffer rings in this table was 93.6% of the country's total land area).

Distance of buffer ring to road[1] (km)	Land area (km^2)	1934 forest area (km^2)	1988 forest area (km^2)	Forest loss (km^2)	Forest loss (%)	
					Relative to total loss[2]	Relative to buffer ring[3]
0.75	68911	21496	4735	16761	17.15	77.97
2.25	42553	17513	4614	12900	13.20	73.65
3.75	30258	15628	4821	10807	11.05	69.14
5.25	22300	13482	4538	8944	9.15	66.34
6.75	21369	14023	5482	8541	8.74	60.90
8.25	16310	11399	5062	6337	6.48	55.58
9.75	13017	9658	4651	5007	5.12	51.84
11.25	11888	9062	4723	4339	4.44	47.88
12.75	10.267	8190	4418	3771	3.85	46.04
14.25	8755	7058	4122	2936	3.00	41.59
15.75	7209	5944	3595	2350	2.40	39.52
17.25	6153	5155	3116	2038	2.08	39.54
18.75	5377	4577	2781	1795	1.83	39.22
20.25	4426	3823	2292	1530	1.56	40.03
21.75	3882	3393	1989	1404	1.43	41.38
23.25	3393	2010	1810	1200	1.22	39.87
24.75	2608	2355	1371	985	1.00	41.80

[1]As measured to the central line of the buffer ring.
[2]The forest loss within a buffer ring relative to the total forest loss during 1934–1988.
[3]The forest loss within a buffer ring by 1988 relative to the forest area within the buffer ring in 1934.

significant ($R^2=0.20$, $P<0.12$). Regions 9, 11 and 12 were among those having the lowest road densities, but they had very high percentages of forest loss (Table 3, Figs. 1 and 3). Conversely, Regions 1 and 3 had high road densities but relatively low percentages of forest loss.

Several factors can help explain this apparent lack of relationship. (1) The effect of roads on deforestation depends not only on the density of roads, but also on their distribution. If roads are too densely distributed in one area but spread out in another area, the impact of these roads will not be as severe as the density suggests because some areas are repeatedly covered by road impact while other areas are remote from roads. The density and the distribution (or pattern) of roads together may explain deforestation better than density alone. For example, in Regions 9, 11 and 12, roads were evenly spread across the regions (Fig. 3), making their impact more severe and leading to high relative forest loss (Table 3, Fig. 1). In contrast, Region 3 had a much higher road density, but most of the roads were concentrated near Manila, and the relative forest loss in this region was lower than that in Regions 9, 11 and 12. (2) The amount of forest to clear is also important when considering

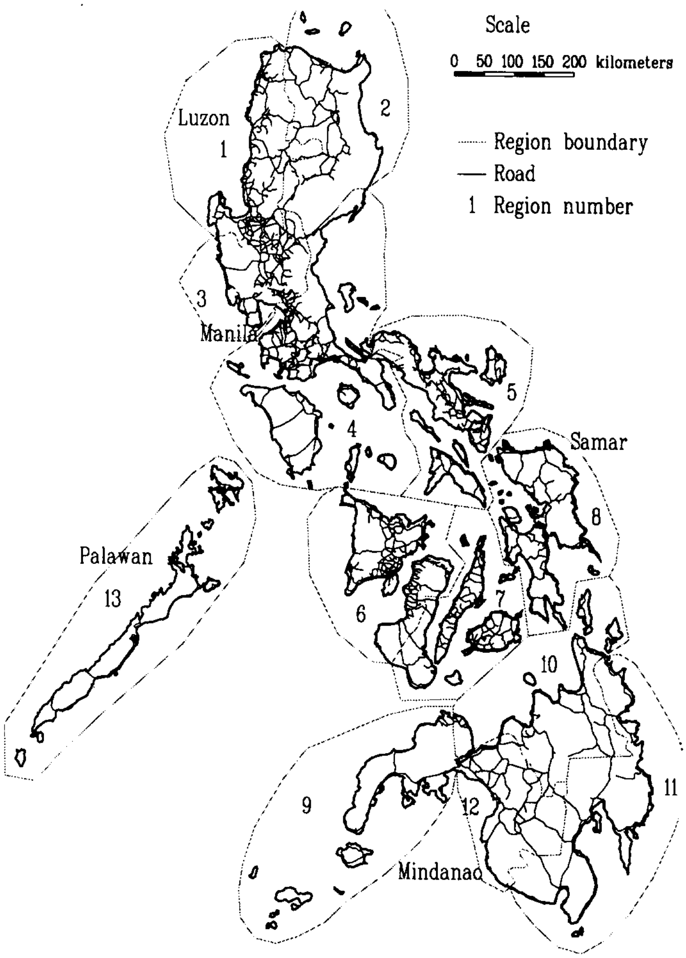

Fig. 3. The Philippine road network in 1941 and administrative regions.

deforestation. For example, in 1934 the forest cover in Region 3 was only 39.7%, compared to 79.3, 86.3 and 78.7% in Regions 9, 11 and 12, respectively (Table 3). (3) The four classes of road quality were assumed to have equal impacts on deforestation in this study. In reality, one would expect differences among road types because good-quality roads might facilitate greater human activity, such as logging (Van der Meer and Ajaloos, 1962).

Deforestation and P/A ratio

The relationship between P/A ratios of the forest patches in 1934 and the relative forest losses during 1934–1988 was significant with a second-order polynomial regression (Fig. 4). Forest patches with a P/A ratio less than 5 m

TABLE 3

Road density and forest loss in each region during 1934–1988 for the Philippines

Region	Region area (km^2)	Total road length (km)	Road density ($km\ km^{-2}$)	1934		1988		Forest loss (%)
				Forest area (km^2)	Percent of land area (%)	Forest area (km^2)	Percent of land area (%)	
1	22961	2404	0.1047	7096	30.9	3768	16.4	46.9
2	33914	1417	0.0418	22007	64.9	14428	42.5	34.4
3	17502	1797	0.1027	6942	39.7	3422	19.5	50.7
4	33600	3148	0.0937	14429	42.9	5779	17.2	59.9
5	17769	1645	0.0926	5902	33.2	1156	6.5	80.4
6	20514	2393	0.1167	5676	27.7	1538	7.5	72.9
7	14520	2096	0.1443	4192	28.9	362	2.5	91.3
8	21343	1767	0.0828	12854	60.2	5434	25.5	57.7
9	17469	646	0.0370	13852	79.3	3178	18.2	77.1
10	26028	1420	0.0546	18012	69.2	9747	37.4	45.9
11	32900	1222	0.0372	28383	86.3	11.343	34.5	60.0
12	23543	1259	0.0535	18531	78.7	5.412	23.0	70.8
13	14678	663	0.0451	12868	87.6	7458	50.8	42.0
Total				170744		73025		57.2

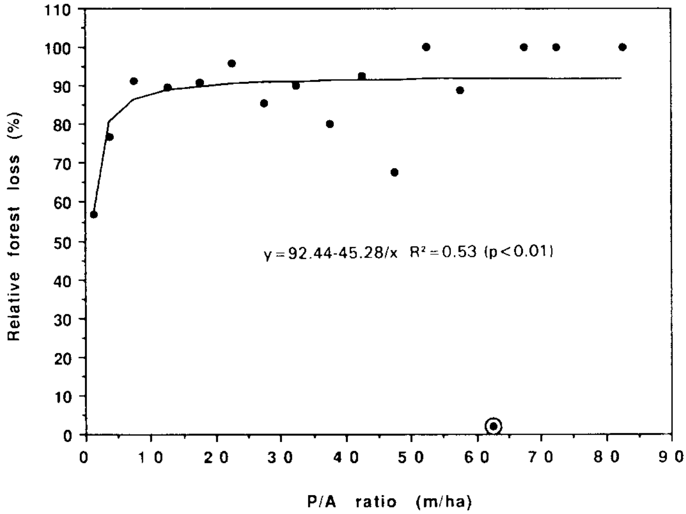

Fig. 4. The relationship between the relative forest losses during 1934–1988 and the perimeter-to-area (P/A) ratios of the forest patches in 1934 for the Philippines. The circled point was an outlier and not used in the regression (see text).

ha^{-1} in 1934 were associated with relatively low percentages of forest clearing. One outlier to this trend (marked by a circle in Fig. 4) was found and was not used to develop the regression. This outlier consisted of two small forest patches whose total area was 100 ha in 1934. A comparison of the 1934 land-use map with the 1988 land-use map showed that these patches fell into a reforested area in 1988. This pattern was very atypical.

Less than 9% of the total forest patches in 1934 had P/A ratios less than 5.0 m ha^{-1} (Fig. 5), but they contributed over 93% to the total forest area in 1934 (Fig. 6). This indicates that these patches were of considerable size, with very little edge (Table 4). Generally, large forest patches had small P/A ratios, and small forest patches had high P/A ratios (Table 4).

There were major changes in the pattern of forest patches in the Philippine forest landscape from 1934 to 1988. In 1934, the forest patches were characterized by various sizes and shapes, as was reflected by the number and area of forest patches grouped into P/A ratio classes (Table 4, Figs. 5 and 6). By 1988, the small forest patches (those with large P/A ratios) which existed in 1934 had all been cleared, and only the large blocks of forest remained. All of the remaining forest patches in 1988 had P/A ratios less than 15.0 m ha^{-1}. The remaining patches of forest had less edge per unit area and were located further from roads; they were therefore less likely to experience continued high rates of deforestation.

During 1934–1988, the number of forest patches with P/A ratio less than 5.0 m ha^{-1} increased by 240% (Fig. 5), while the area of the forest patches for this P/A ratio range decreased by 61% (Fig. 6, Table 4). The average size

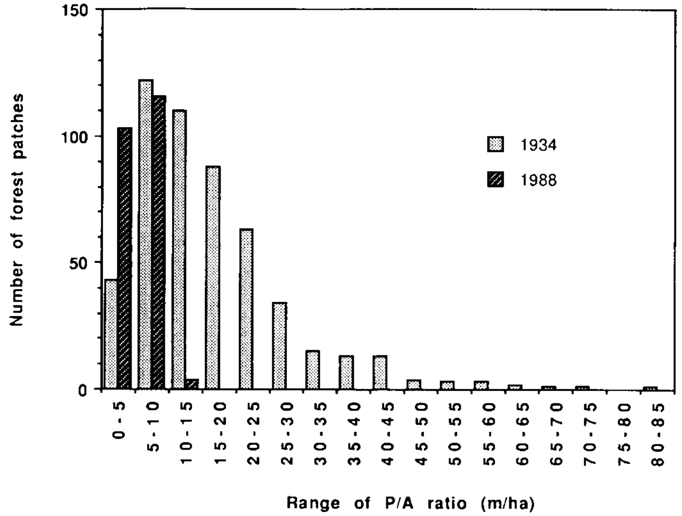

Fig. 5. The number of forest patches by perimeter-to-area (P/A) ratio classes in 1934 and 1988 for the Philippines.

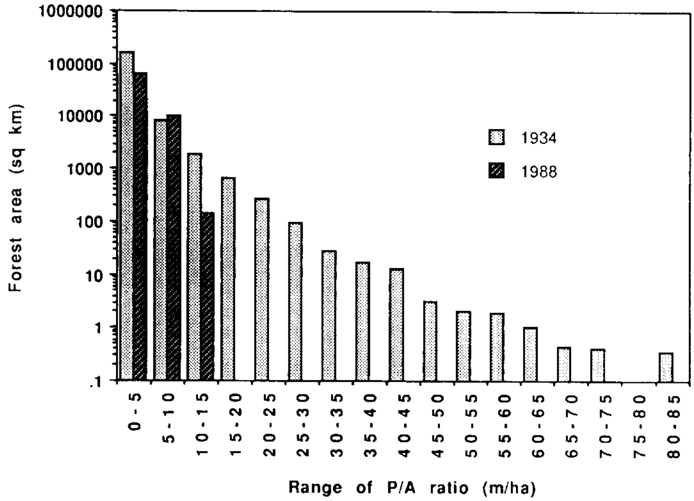

Fig. 6. The area of forest patches by perimeter-to-area (P/A) ratio classes in 1934 and 1988 for the Phillipines. Note that the vertical scale is logarithmic.

TABLE 4

Average size of the forest patches in 1934 and in 1988 for the Philippines

Range of P/A ratio (m ha^{-1})	Average patch size (km^2)	
	1934	1988
0.0–5.0	3711.70	606.09
5.0–10.0	66.43	89.10
10.0–15.0	17.92	35.14
15.0–20.0	7.29	–
20.0–25.0	4.13	–
25.0–30.0	2.66	–
30.0–35.0	1.83	–
35.0–40.0	1.31	–
40.0–45.0	1.00	–
45.0–50.0	0.78	–
50.0–55.0	0.67	–
55.0–60.0	0.63	–
60.0–65.0	0.50	–
65.0–70.0	0.43	–
70.0–75.0	0.40	–
75.0–80.0	–	–
80.0–85.0	0.36	–

of a forest patch with a P/A ratio of 0.0–5.0 m ha^{-1} decreased from 3711.7 to 606.1 km^2. This meant that the large forest patches in 1934 were encroached upon and/or fragmented and became smaller forest patches by 1988.

Although the P/A ratio is theoretically a good indicator for analyzing patterns of forest change, there are some practical problems. For example, the theoretical conclusion that a large P/A ratio leads to a high percentage of forest clearing, as was found in this study, is based on the assumption that forests are encroached upon from around all the edges of a forest patch. This, however, is not always true. The distance of a forest to roads is also important. Furthermore, the presence of preserved forest reserves leads to exceptions to these trends (Bunge, 1984). These factors were not included in this study.

CONCLUSION

In summary, the accessibility and proximity of forests to human activity are two mechanisms that explain the depletion of tropical forests in the Philippines between 1934 and 1988. The distance of a forest to roads was the most important factor because roads provide the means to readily transport people into a forested area.

The presence of transportation networks in tropical forest areas has always led to deforestation, partly because road networks in colonial countries were designed to extract resources not to trade within the country. Before the construction of large road networks in the tropics, rivers were generally used to gain access to the interior of forests, as witnessed by the development of population and agricultural production centers along major rivers, e.g. the Amazon (Bates, 1989). As colonization of tropical lands spread, road networks were constructed to connect towns, production centers, etc., providing greater access to forests with concomitant increases in deforestation. Today, environmental groups often oppose road construction into tropical areas because of the increased potential for deforestation to occur in these areas

The relationship between roads and deforestation is further illustrated in logging operations in tropical forests. Logging is often cited as a cause for deforestation, but in reality it is often the construction of logging roads and poor forest protection that is the cause. Logging roads enable landless people to enter the previously inaccessible areas and clear these logged forests, often through slash and burn activities.

With respect to the Philippines, one of the largest forest tracts still present is in Palanan, northeast Luzon (Fig. 1), due in part, most likely, to the absence of roads (Fig. 3, Abate, 1992). Logging interests are pressing the government to build a road into the area, but many believe that this would be a disaster and lead to increased deforestation (Abate, 1992).

Fragmentation of forests is another important factor because small patches which have large P/A ratios and are surrounded by agricultural or other nonforest lands are more readily cleared than large blocks of forest. Higher rates of forest degradation have been shown to be linearly related to increasing fragmentation in Peninsular Malaysia (Brown et al., 1992).

Results from this study have practical implications for managing and monitoring tropical forest landscapes. Large blocks of forest with small P/A ratios and limited access by roads stand a good chance of being little disturbed by humans (e.g. Palanan region in the Philippines). However, restriction of road construction is often counter to development schemes in tropical countries. Therefore, the next best thing is to ensure that fragmentation is minimized and that forests designated for conservation are not fragmented (have small P/A ratios).

This study also demonstrates how remote sensing can be used to identify areas susceptible to deforestation. If major roads can be identified and P/A ratios of forest patches can be calculated by interpreting imagery from satellites or aircraft, then the forest patches close to roads and having high P/A ratios are most likely to be cleared. Remotely sensed images have advantages over land-use maps because the data contained in the former are more timely and they can be more readily entered into a computer for processing and analysis.

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